Advanced Scanning Technology for Imaging Radars (ASTIR)

H. Bruce Wallace, STO PM

Proposers Day

18 August 2014

DISTAR Case #23357

Agenda

0815-0900	Registration
0900-0915	Sign-in, Welcome and Introductions; Security Overview - Bruce Wallace, Michael Harpin
0915-0945	DARPA/STO Overview - STO Director Dr. Nils Sandell
0945-1000	Contract Management Office Guidance - Tina Stuard
1000-1045	ASTIR - Bruce Wallace
1045	End of Plenary Session (Room 01-200 will remain open)
1100	First set of One-on-One sessions in room 01-400
1230	Lunch Break
1300	Second set of One-on-One sessions in room 01-400
1630	Adjourn

Advanced Scanning Technology for Imaging Radars (ASTIR)

An opportunity exists to create a new imaging radar architecture which will:

- Provide high resolution 3D imaging for enhanced identification and targeting; independent of platform or target motion
- Produce video frame rates (>10 Hz) to compensate for image/target motion
- Reduce system complexity resulting in lower cost, power, and weight

ASTIR will result in more readily available, cost effective imaging radar capabilities for:

- Terminal homing seekers
- Target classification for force protection
- Personal imaging for detection of concealed weapons
- Other applications ?

ASTIR will exploit recent developments to create a new imaging radar architecture

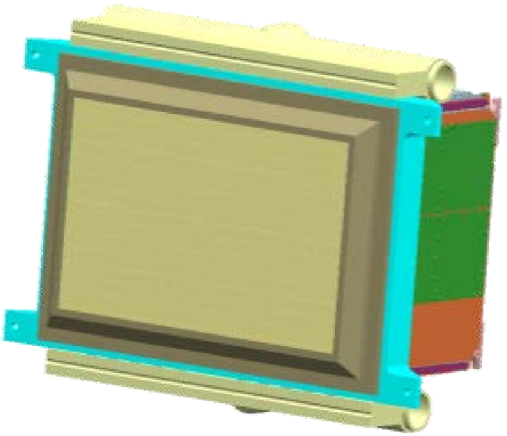
Current techniques for radar imaging

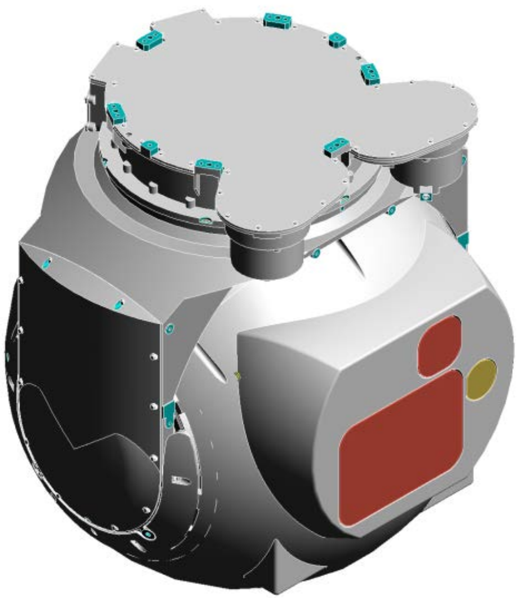
Electromechanical - simple but slow

JPL 670 GHz Imager with electro-mechanically scanned sub-reflector

Phased array – fast but complex

DARPA MFRF Radar for Rotorcraft – 25,000 elements



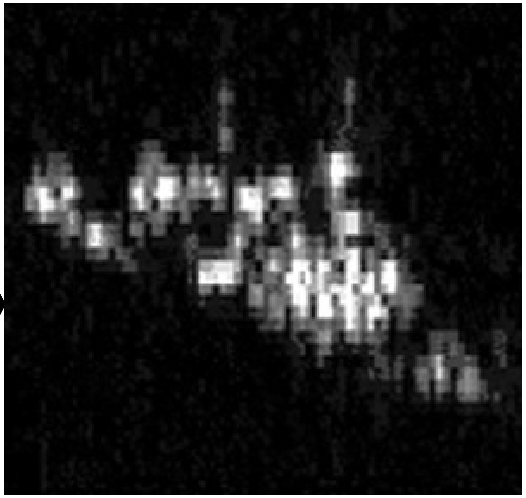


Synthetic Aperture Radar (SAR) – requires platform motion

DARPA ViSAR Concept in MTS-B Gimbal

Inverse Synthetic Aperture Radar (SAR) – requires target motion

ISAR ship image from Raytheon



A comparison of radar imaging techniques

Imager	Strengths	Weaknesses
SAR	Moderate complexity – 2-8 channels	Requires platform motion 2D imaging
ISAR	Low complexity - single RF channel	Requires target motion 2D imaging
Electro-mechanical	Single RF channel with simple mechanical scanning 3D imaging	Low frame rate High SWaP of electro-mechanical parts Vibration disrupts image formation
Phased array	High frame rates Employed from fixed or moving platforms 3D Imaging	High complexity – many RF channels Element spacing above 100 GHz
ASTIR	High frame rates Employed from fixed or moving platforms Low complexity - single RF channel 3D Imaging	TBD

Utilize key strengths and reduce complexity

Component count as a measure of complexity

Imager	Frame Rate	Active devices per Pixel (N)	Total for an Example Image Size 128x128 (16384 pixels)
Phased array	0.5 Hz (X-Band) 10 Hz (MFRF)	4T + 5R +1D	163,840
ASTIR	1-100 Hz	1N + (4T + 5R +1D)/N	16,394

T = Transmitter component, R = Receiver component, D = Diplexer

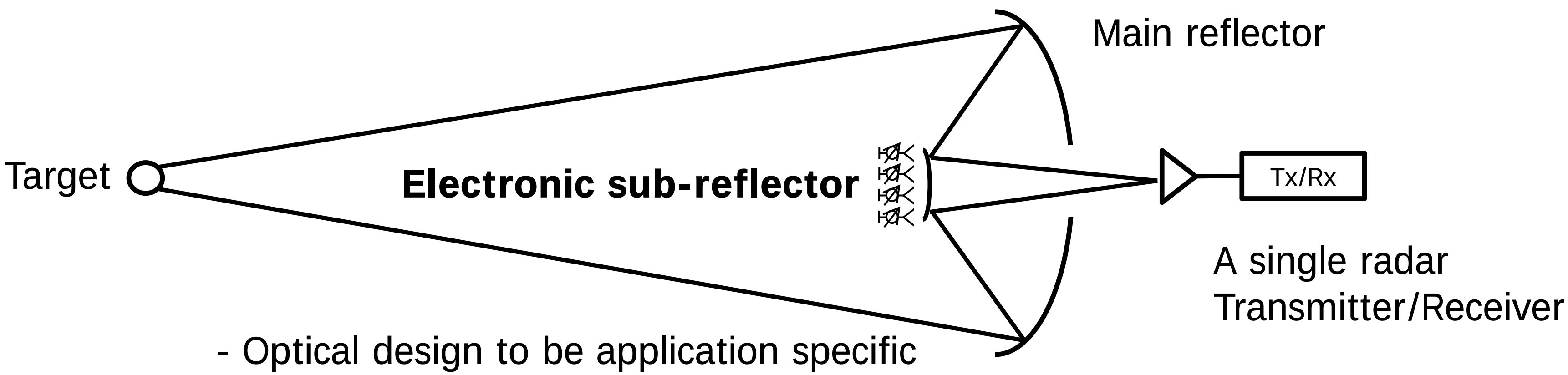
Component count does not include signal and image processing

ASTIR would reduce build complexity by <u>10x</u> over phased arrays while maintaining high frame rates

Proposed new architecture for imaging radar

A radar with a compound antenna structure:

- A primary aperture large enough to achieve required resolution
- An electronically scanned sub-reflector to provide high resolution within the Field of View (FOV)



Approach 1: Sub-reflector replaces an electro-mechanically scanned mirror

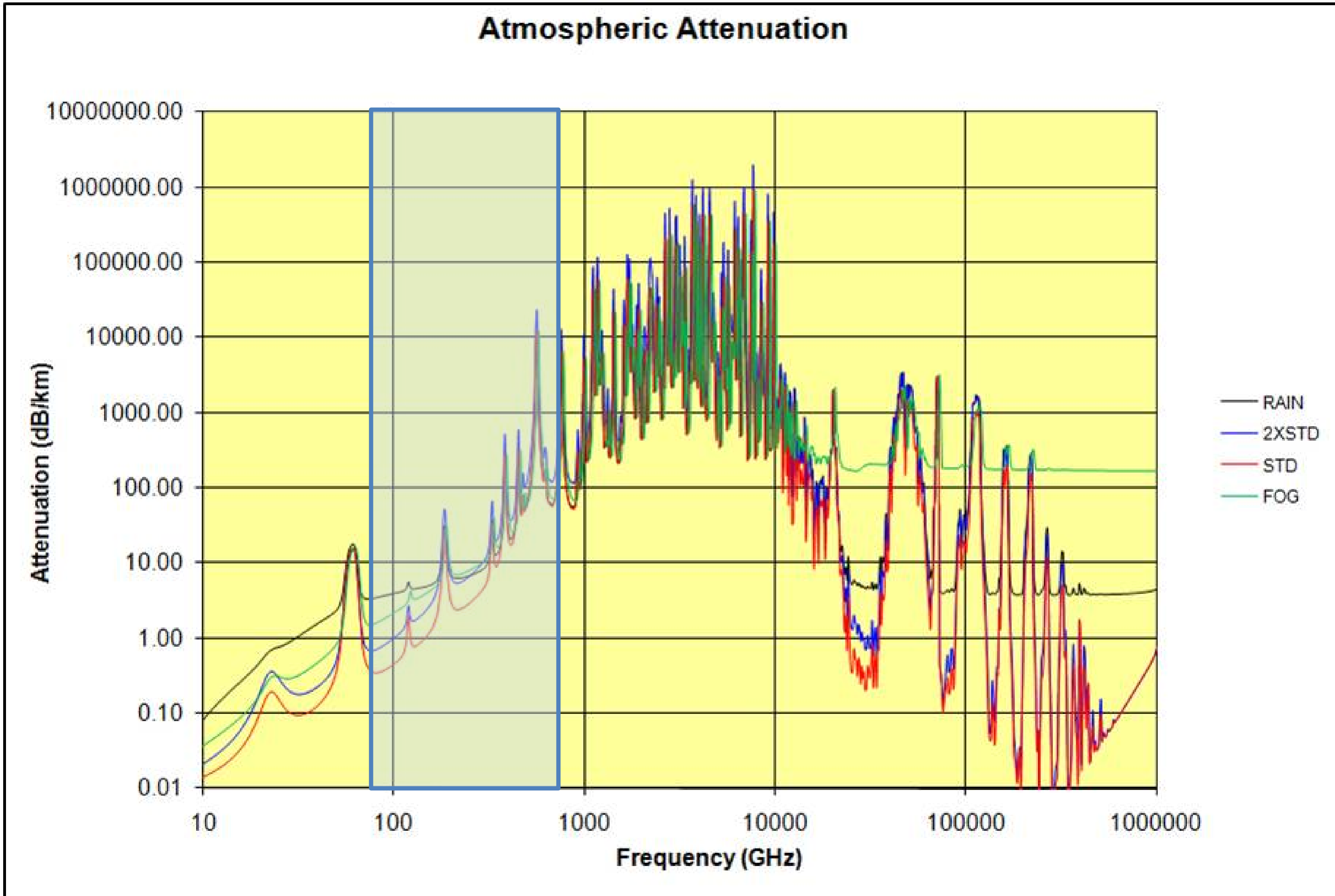
Approach 2: Sub-reflector electronically steers a small spot across the main reflector

- RF sampled at each spot location is processed using synthetic aperture techniques to reconstruct an image at any range in the FOV - digital image formation

Approach 3: Elements of the sub-reflector would be digitally modulated with orthogonal phase codes

- Electric field on each element would be decoded after reception and processed to permit digital beamforming

Atmospheric attenuation from 10 GHz (2cm) through 10^6 GHz (0.3 microns) for four weather conditions



ASTIR technical challenges

Sub-reflector technology

Challenges:

- Achieving required element spacing at Extremely High Frequencies (EHF)
- Fabrication of surface areas sufficiently large enough for sub-reflectors
- Amplitude and phase granularity at each element

Goals:

- Frequency range – 70-700 GHz
- Manufacturable Area - ≥ 0.2 m x 0.2m (0.04 square meters)
- Instantaneous bandwidth – 5%
- Scan angle - ± 45 degrees
- Switching speed < 1 μsec

Processing technology

Challenges:

- Phase/amplitude control for beam steering and shaping across band
- Rapid 3D Image formation at high framing rates
- Compensation of target and/or platform motion
- Calibration of sub-reflector elements

Goals:

- N x M x R pixels/sec – dependent on sensor concept
- Phase/Amplitude control – dependent on scan approach

The greatest challenge will be creating the controllable sub-reflector

- **Technical Area 1 (TA1) Develop Electronic Sub-Reflector Approaches**
  - Phase 1 (6 months): Develop the design for an electronic sub-reflector for a compound antenna with a single transmit/receive chain.
    - Multiple awards anticipated.
  - Phase 2 (18 months): costed option to develop and test the prototype electronic sub-reflector system designed in Phase 1.
    - At least one performer anticipated to continue into Phase 2

- **Technical Area 2 (TA2) - Sensor System Designs and Processing Algorithms.**
  - Develop sensor system designs and processing algorithms
  - Single Phase (12 months)
    - Multiple awards anticipated

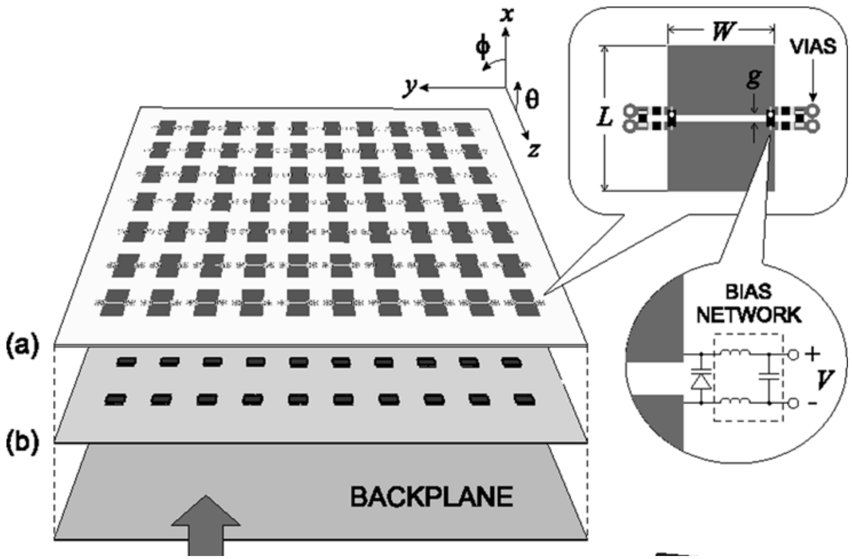
- For a specific application, the selection of frequency is a tradeoff between frame rate, atmospheric losses, and distance requirements. This program focuses on the technology applicable over the frequency space from 70-700 GHz.
- Proposers are free to submit proposals for either a single technical area or for both technical areas. If proposers submit proposals for both technical areas, then these should be submitted as two distinct proposals, one for the first technical area and one for the second technical area.

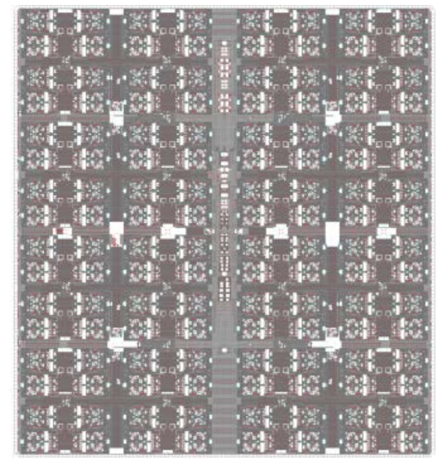
TA1: ASTIR electronic sub-reflector goals

At a minimum, the system goals will include the parameters below
(example values provided for clarity only):

- Frequency range over which technology is applicable. Example: 70-340 GHz
- Manufacturable Area. Example value: ≥ 0.2 m x 0.2m (0.04 square meters)
- Instantaneous bandwidth. Example: at least 5%
- Scan angle. Example: ± 45 degrees
- Switching speed. Example: < 1microsecond
- Power handling. Example: > 100mW/cm^2.
- RF Loss. Example: < 2 dB one-way
- Cost to produce ??

One electronic sub-reflector approach - Varactor arrays





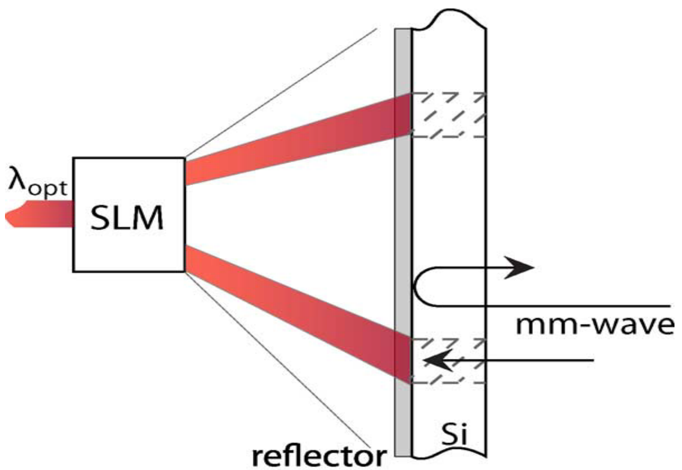
94 GHz MFRF beamformer

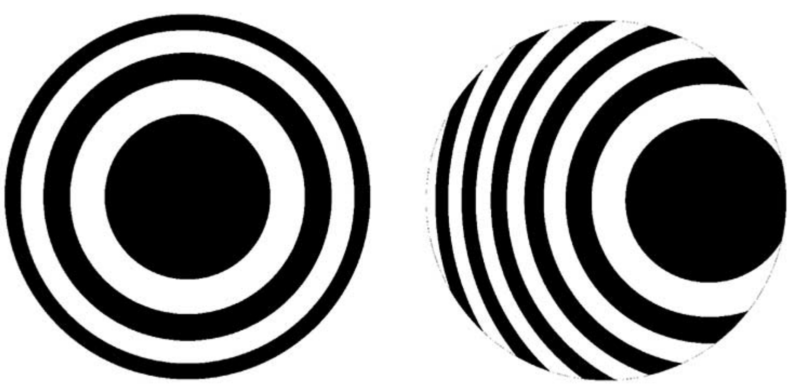
- Arrays of patch antennas with integrated phase shifting diodes have been demonstrated at microwave frequencies
- Recently developed pick and place tools could provide the capability to extend this approach into the MMW/THz regime

- MFRF has developed extremely dense active arrays at 94 GHz but SiGE active arrays are currently not viable at significantly higher frequencies
- Since the reflecting array does not use the devices for gain, silicon processes may prove viable for this application beyond 400 GHz

Another sub-reflector approach – Laser induced zone plates

- Laser with a spatial light modulator illuminates high resistivity silicon wafer
- Zone plate pattern (Hologram) is induced in silicon
- MMW energy reflects off of disk in a direction depending on the pattern
- Scanning speed is proportional to laser power and silicon resistivity





On- and off-axis zone plate pattern written on silicon disk

"The Photo-Injected Fresnel Zone Plate Antenna: Optoelectronic Beam Steering a mm-Wave Frequencies"
Tom F. Gallacher, *et al* , IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 4, APRIL 2013

ASTIR will invite proposals for any suitable technology to meet the sub-reflector goals

TA2 - Sensor System Designs and Processing Algorithms

Image formation

- Processing of data for specific applications and approaches
  - Beamsteering and correction for beam steering with frequency
  - Quadratic phase control and amplitude weighting for beam shaping
- Processing of data for large depth of focus
  - Rapid refocusing at the reflector vs refocus digitally on receive
- 3D Image formation at high framing rates
  - High frame rates permit freezing targets to permit better motion compensation
- Focusing of moving targets and possible platform motion
  - Using the motion of targets (ISAR) and platform (SAR) permits increased resolution and improved Signal-to-Noise Ratio (SNR) at lower rates required for identification

Investigations into these processing challenges will be carried out in parallel with the sub-reflector development and demonstration.

Elements of the program

BAA 14-53: Sub-reflector Technology Development

Industry and Academia

TA1: Develop sub-reflector technology for rapid control of radar beam characteristics

- Phase 1 - Design an electronic sub-reflector for a compound antenna with a single transmit/receive chain
- Phase 2 – Build and demonstrate a prototype electronic reflective scanner

TA2: Investigate sensor designs and processing approaches

Mission Analysis

APL, IDA, Lincoln Lab, Navy, PNNL

- Determine specific applicable military needs
- Develop requirements for BAA 2

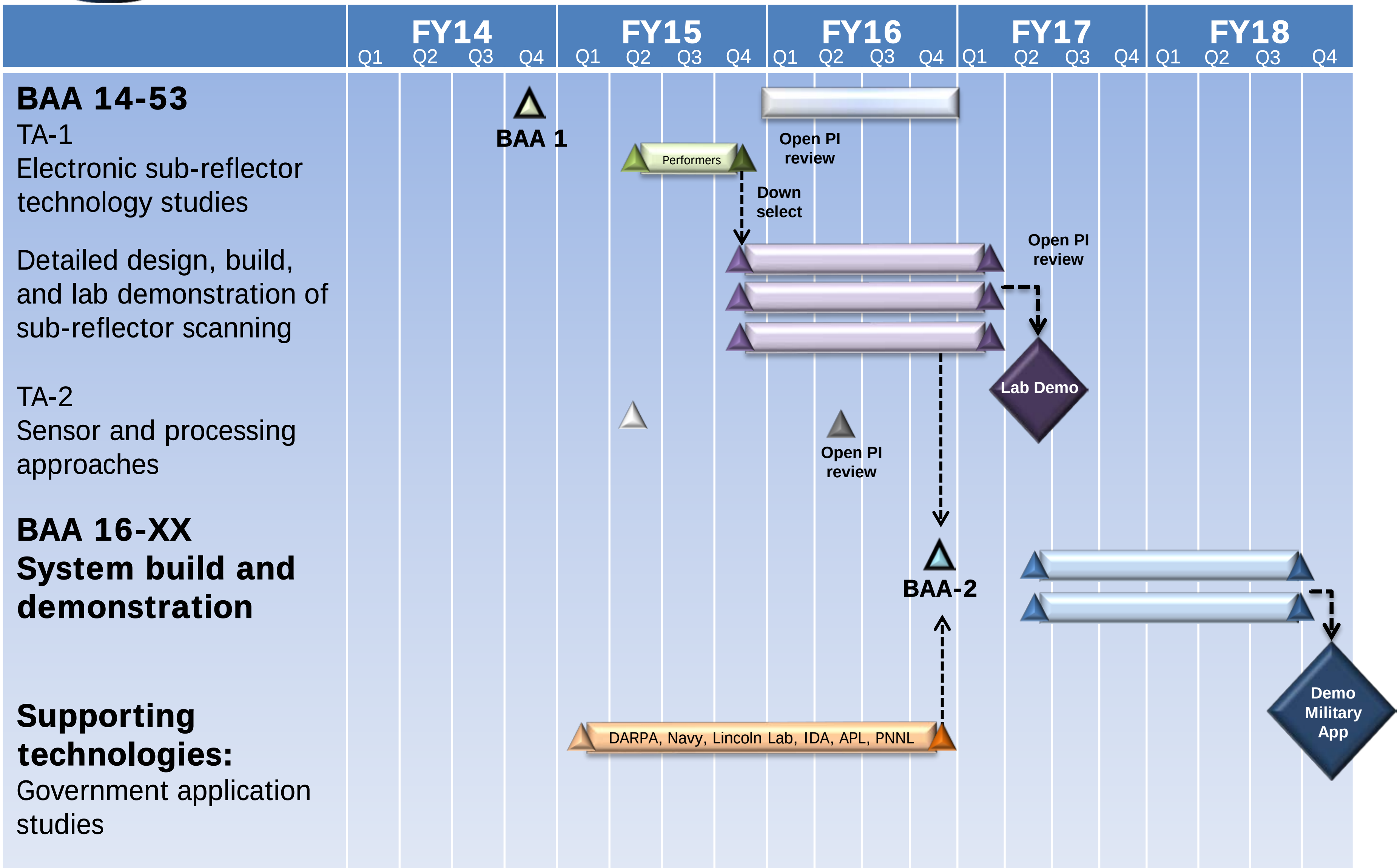
BAA 2 (FY16): Develop and demonstrate sensor for military missions

1-2 demonstrations of sensors for specific military applications

Potential applications

- Defense of in the Littoral environments (small boat attack)
- Defense of land facilities against local incursion
- Monitoring personnel passage through access points in facilities
- Terminal Homing

ASTIR program plan



Role of Principal Investigator (PI) meetings

- Each Phase of the Technical Area 1 Effort will conclude with a Principal Investigator's (PI) meeting
- Technical Area 2 effort (single phase) will also conclude with a PI meeting
- Proposers should identify any restrictions that they will have on briefing their results at the PI reviews.

Intellectual Property Considerations

- Proposers should identify any intellectual property claims associated with their approach and any restrictions on deliverables.
- The Final Reports and other reporting deliverables should have a main body that does not include any restrictions. If there are materials with data rights restrictions these materials should be included in annexes.

BAA-14-53 Dates

ASTIR BAA-14-53 Key Dates	
BAA Release	8/04/14
Proposer’s Day	08/18/14
Abstracts Due	08/26/14
Last date to submit questions	09/26/14
Proposals Due	10/10/14
Notification of Selection	~11/10/14
Contract Award	Feb-March 2015

References

- Berry, D. g. R. G Malech, and W. A. Kennedy, “The Reflectarray Antenna”, *IEEE Transactions on Antennas and Propagation*, vol. 11, pp. 645–651, 1963.
- Gallacher, Tom F. et al, “The Photo-Injected Fresnel Zone Plate Antenna: Optoelectronic Beam Steering a mm-Wave Frequencies” *IEEE Transactions on Antenna and Propagation*, Vol. 61, No. 4, April 2013.
- Tamminen, A, T. F. Gallacher, et al, “Developments of reflectarray and its element characterization at millimeter wavelengths”, *Proceeding of SPIE Vol 9078*, “Passive and Active Millimieter-Wave Imaging XVII”, May 2014.

Additional Questions

Please submit any outstanding questions you have to our BAA inbox at:

DARPA-BAA-14-53@darpa.mil

Thank you for your time and interest in ASTIR, we look forward to hearing your ideas.